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14. ABSTRACT
We neared completion of a new instrument for measurements of habit-diameter-mass-fallspeed relationships for hydrometeors. Such relationships are essential for accurate radar retrievals and numerical simulations of storms. Completion of the Multi-angle Snowflake Camera (MASC) will provide for the first time automated measurement of these properties. The instrument is currently at a stage suitable for lab-bench tests. Further support is needed to cover completion of an outdoor version of the probe, software development and scientific analysis of results

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List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Number of Papers published in peer-reviewed journals: 0.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Presentations

Number of Presentations: 0.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts): 0

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Patents Submitted

Fallgatter, C. and T. J. Garrett, 2009: Systems and methods for imaging of falling objects.

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Timothy Garrett	0.00	No
FTE Equivalent:	**0.00**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

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The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME
Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED	
Cale Fallgatter	1.00	No
FTE Equivalent:	**1.00**	
Total Number:	**1**	

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Technology Transfer

Development of the Multi-Angle Snowflake Camera for Improved Hydrometeor Habit-Diameter-Mass-Fallspeed Parameterizations

Tim Garrett

Associate Professor of Atmospheric Sciences, University of Utah

May 20, 2011

Abstract

We neared completion of a new instrument for measurements of habit-diameter-mass-fallspeed relationships for hydrometeors. Such relationships are essential for accurate radar retrievals and numerical simulations of storms. Completion of the Multi-angle Snowflake Camera (MASC) will provide for the first time automated measurement of these properties. The instrument is currently at a stage suitable for lab-bench tests. Further support is needed to cover completion of an outdoor version of the probe, software development and scientific analysis of results obtained in high-desert mountainous terrain.

1 Project Goals

Proposal goals

We aim to improve radar retrievals and numerical forecasts of cold weather storms, particularly in mountainous regions in high deserts. To this end, this proposal seeks support to complete construction and development of a new instrument aimed at automated characterization of falling hydrometeors. Our Multi-angle Snowflake Camera (MASC) design permits multiple high-resolution images of a single hydrometeor to be captured in free fall, by positioning five cameras at different angles spread over 150°, each converging on a common focal point. The camera system is triggered by infrared sensors that detect a snowflake as it falls through the focal point. A bank of infrared detectors provides measurements of hydrometeor fall-speed and rotational velocity.

MASC measurements will enable automatic characterization of the relationships between hydrometeor habit, diameter, mass and fall-speed: key parameters for accurate radar retrievals and numerical modeling of storms. We are seeking support to complete development of an instrument prototype, develop related software, field test the instrument and obtain new parameterizations.

Motivation

Radar retrievals and mesoscale model forecasts rely heavily on parameterized relationships between hydrometeor habit, diameter, mass and fallspeed (Matrosov et al., 2002; Stoelinga et al., 2003; Shupe et al., 2006). The lifetime of a simulated storm and the amount of precipitation it produces is highly sensitive to the parameterized rate of condensate removal (Reisner et al., 1998). Yet the extreme complexity of potential microphysical processes involved makes implementation of well-founded parameterizations a continuing challenge.

Prior research into habit-diameter-mass-fallspeed relationships of snow particles has used one of two approaches. One is primarily theoretical, and calculates fall speed based on sophisticated fluid dynamic considerations for idealized particle shapes (e.g. Mitchell, 1996). While the problem is solvable in principle, through aggregation and riming, snowflakes are rarely composed of simple, symmetric shapes (Korolev et al., 1999; Korolev et al., 2000), and even when they are "pristine", turbulence makes them effectively infinitely variable in form (Nelson, 2008).

The second approach is to empirically derive mass-fallspeed relationships for ensembles of loosely categorized snowflake habits (e.g. graupel, stellars, etc.). For example, parameterizations of habit-diameter-mass-fallspeed relationships used in such mesoscale models as MM5 and WRF (e.g. Reisner et al., 1998) rely on a single decades-old empirical study by Locatelli and Hobbs (1974). Locatelli-Hobbs was superb work, based on a painstaking manual examination of falling snow collected at low elevation (700 m to 1500 m) in the Washington Cascades. But, by today's standards, the methods were primitive, and the statistical validity of the data acquired was limited by human constraints.

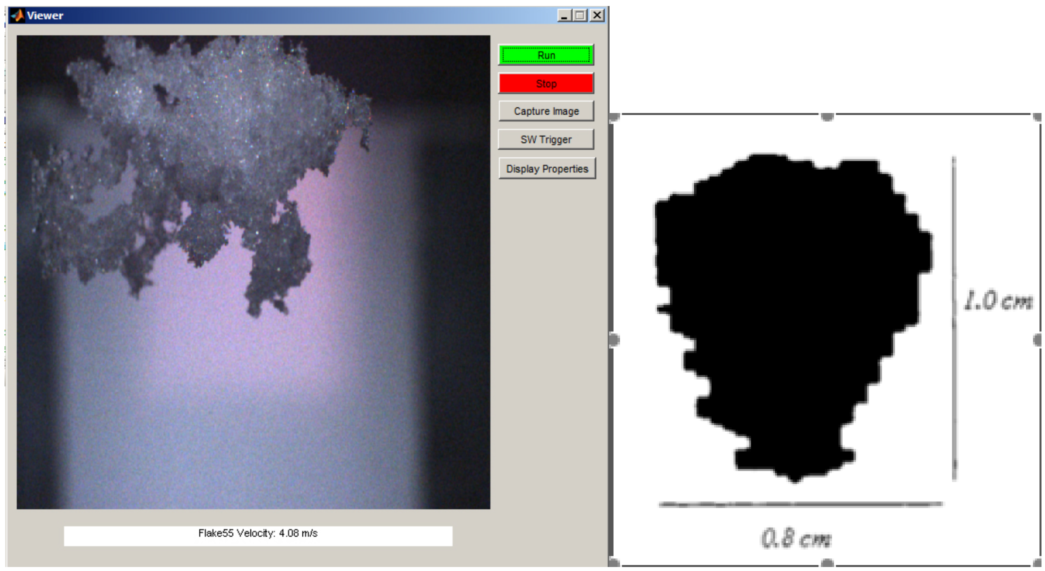

Figure 1: A development-stage lab-bench screenshot of simultaneous image and fall-speed (image bottom) capture from the MASC of falling snow from a cup (left, ~1 cm across). Current best available imagery of graupel using the HVPS (right).

Newer, more objective, and more powerful technologies can be used to characterize mass-fallspeed relationships, and are needed to extend results obtained in the warm, wet Cascades where Locatelli and Hobbs obtained their data to drier environments, for example in current military arenas in Afghanistan.

2 Comparison with prior development

Currently, there is no instrument available that can both image hydrometeors, measure their mass, and provide their fall-speed in the precipitation size range. The primary in-situ probes available today are a Cloud Particle Imager (CPI), which provides nominal 2.5 μm resolution photographs of cloud particles between up to 0.2 cm across. The 2D-S provides 10 μm resolution silhouettes of particles up to 0.3 cm across. The HVPS and 2D-P provide 200 μm resolution silhouettes of particles with sizes up to 6 cm across.

By contrast, the Multi-Angle Snowflake Camera or MASC we are developing provides actual photographs of hydrometeors within the 0.1 to 2.5 cm size range that would normally be covered by silhouettes from the HVPS and 2D-P. Further, the MASC size range can be adjusted easily with zoom or macro lens fittings. As shown in Fig 1, particle habit identification in this size range can be substantially improved.

Larger crystals greatly benefit from finer resolution because rimed droplets and the branches of dendritic snowflakes typically have dimensions smaller than the HVPS resolution of 200 μm. Also, where the HVPS provides black silhouettes, the MASC, by contrast, provide photographs of transmitted and reflected light.

In addtion, no hydrometeor imager is currently available that provides detailed stereography required to infer particle mass, nor is an instrument available to provide simultaneous particle fall-speed. The MASC will fill this gap.

2.1 Detailed MASC description

We have submitted a patent application for the Multi-Angle Snowflake Camera entitled "Systems and Methods for Imaging Falling Objects" (Fallgatter and Garrett, 2009). The data capturing potential of the MASC is unprecedented in snowflake research. The current stage of development showing high-resolution photography and particle fall-speed is illustrated in Fig 1. The following is a list of data that can be collected for hydrometeors at the point that MASC development is completed.

- Stereoscopic polarized color images – Color and polarization enhances snowflake appearance. Individual falling snowflakes will be imaged from five different angles spread over 150° for stereoscopy. Using high resolution (UXGA), color, Sony cameras (XCDU100CR), each camera will capture simultaneous images of falling snowflakes at a maximum resolution of 10 μm at 1/100,000th second shutter speed.
- Volume and mass – Calculated through stereoscopic reconstruction.
- Fall speed – Vertically stacked motion sensors provide snowflake fallspeed information
- Spatial orientation and rotation – Having an array of motion sensors provides information of the spatial orientation and rotation of snowflakes.

Thus, the MASC will provide all necessary measurements to provide automated calculation of habit-diameter-mass-fallspeed relationship for hydrometeors.

3 Remaining tasks

With external support, we intend to

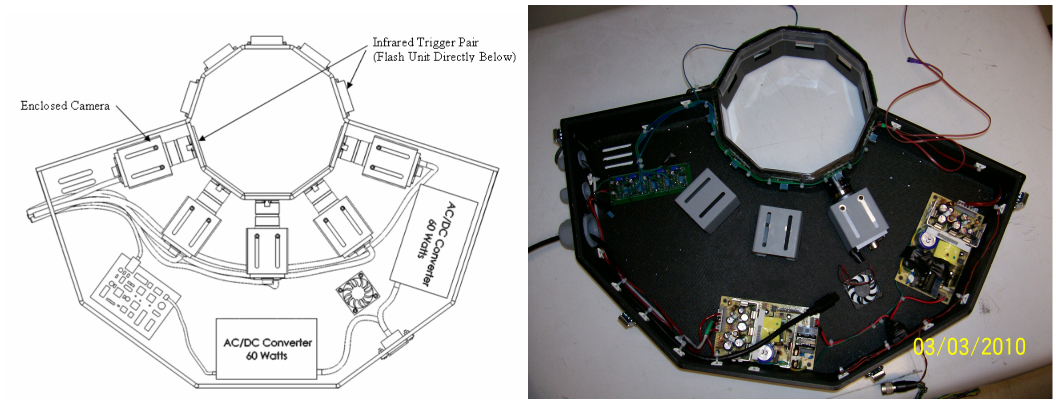

Figure 2: Plan view of the MASC

1. Complete development of the MASC in a form suitable for atmospheric conditions.

2. Test the MASC at the the P.I.'s Cloud Physics lab at the University of Utah and our High Altitude Research Laboratory for Diversity in Snow (HARoLDS) at 3010 m at the Alta Ski Area.

3. Develop software for 3D reconstruction of snowflake volume from stereoscopic snowflake images. We will use a method for reconstructing complicated snowflake volumes by applying a Marching Cubes Algorithm (Matsuyama et al., 2002) to multi-angle gray-scale snowflake photographs Takizawa et al. (2005).

4. Based on a season's observations at HARoLDS, develop new parameterizations for relating hydrometeor habit, diameter, mass and fall-speed

4 Field testing

We run the High Altitude Research Laboratory for Diversity in Snow (HARoLDS), located at "Harold's Cabin" at 3010 m altitude in the Wasatch Mountains, within the Alta Ski Area bounds just 40 minutes drive from the University of Utah (Fig. 3). HARoLDS receives in excess of 500 inches of snowfall every winter.

HARoLDS is located in a sheltered area and is just above a long-term scientific snow study plot (Steenburgh and Alcott, 2008). Over the past season, we have obtained fully automated measurements of snowflakes snowflakes in free-fall using an immensely more primitive instrument than the MASC called the HYVIS. An illustration of

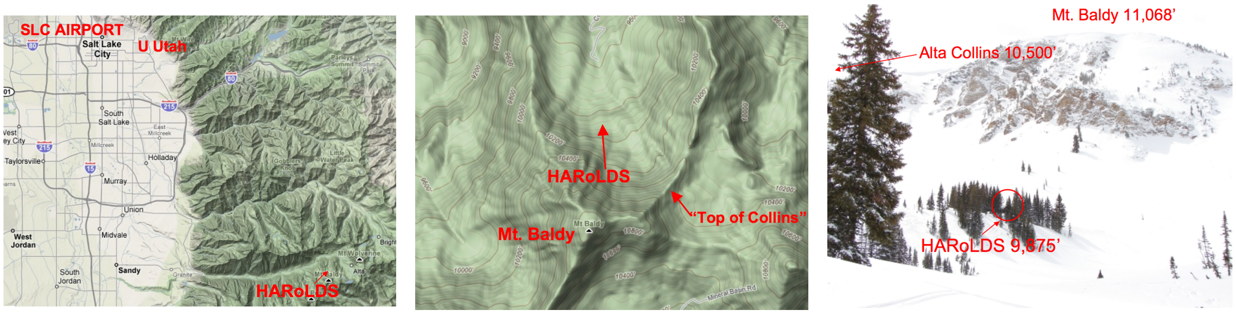

Figure 3: Location of HARoLDS field site

HYVIS capabilities at HARoLDS is shown in Fig. 4. The MASC will provide vastly improved stereographic images and fallspeed.

Thus, we have all necessary facilities in place to do long-term automated winter storm characterization of hydrometeors. Placement of the MASC at HARoLDS will enable us to obtain automated habit-diameter-mass-fallspeed relationships required for successful military forecasts and retrievals of cold weather storms. Ultimately the instrument will be available for use in a wide range of environments. The military benefit of placing the MASC at HARoLDS is that will provide excellent statistics in a climatological regime representative of the snowfall characteristic of arid mountain environments.

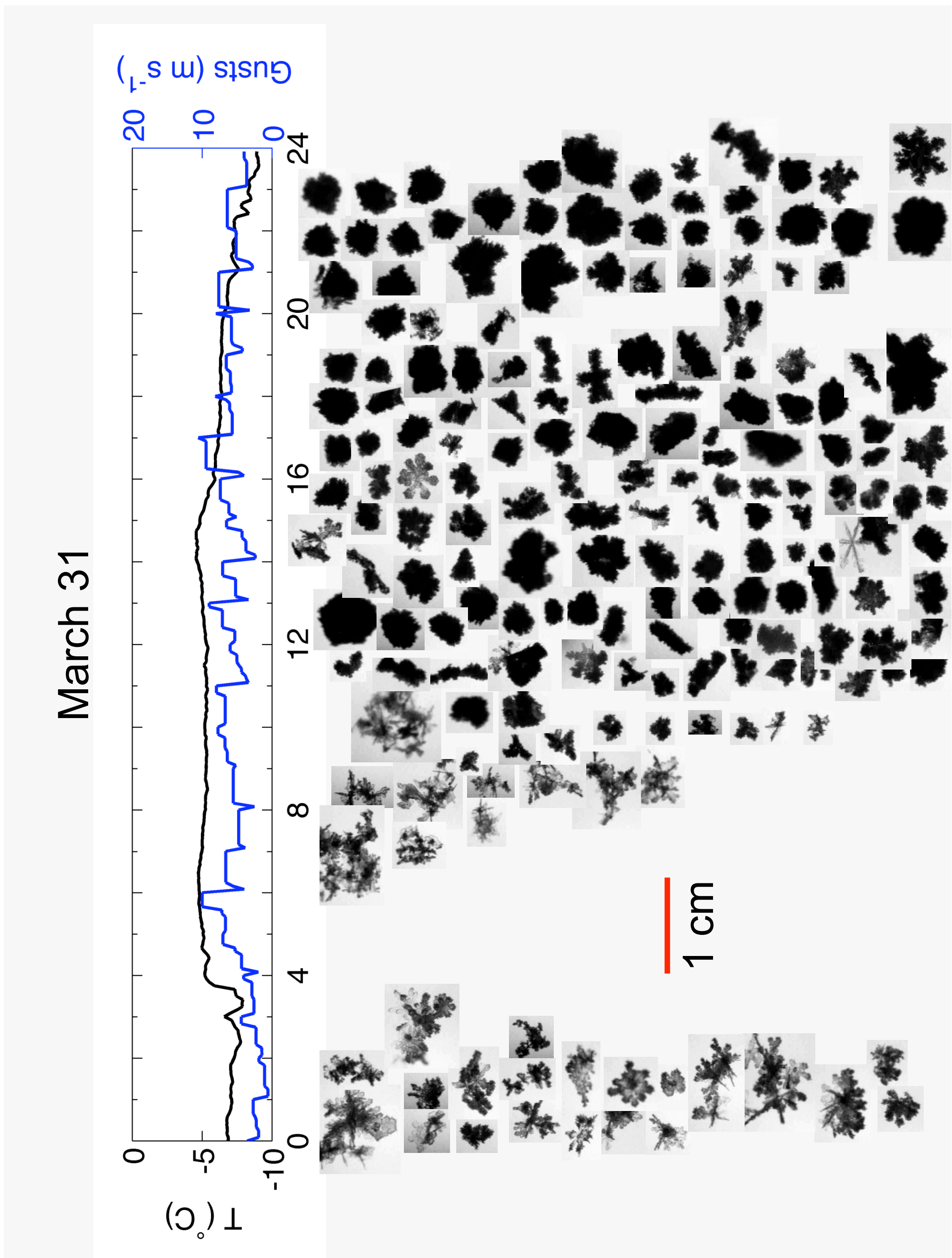

Figure 4: Operational imagery obtained at Alta Ski Area on March 31 using a primitive precursor to the MASC, the HYVIS.

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